Snowmass 2013 Instrumentation Frontier
Brief Summary

G. Haller, 8-23-13

A few slides from the meeting about

- Challenges/technologies in energy, cosmic, energy frontier areas
- Areas of R&D
- CPAD (Coordinating Panel for Advanced Detectors)

Energy Frontier – LHC

(ILC/CLIC & Muon collider slides in backup)

Focused Challenges:

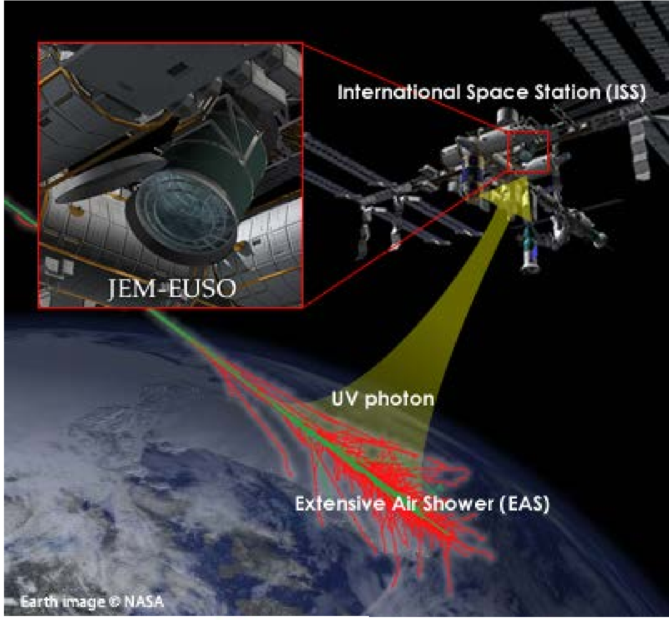
- Maintain detector performance in the presence of 140 int/xing
  - Low mass tracking
  - Fast timing
  - DAQ
- Extend forward calorimetry and tracking to η=4 for WW scattering and HH studies
- Radiation hardness

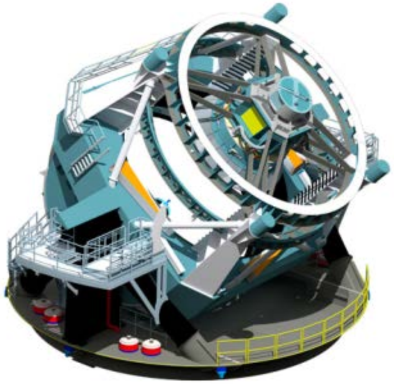
Technology Area	What is needed	Implementation
Pixelization	Lower occupancy Track primitives	Tracker segmentation Track stubs, ROI
ASIC and electronics	Inner pixel IC	65 nm rad hard designs Low power design
Trigger and DAQ	Track triggers High BW optical	Assoc. memory Mach Zender modulators
Mechanics and power	Cable mass Cooling to -25 deg	DC-DC/serial power Co2, carbon foams
Photosensors	Rad hard compact sensors	SiPMs
Speed	isolate primary vertex	10 ps resolution tof
Sensors	Rad hard, pixelated	Thin silicon 3D silicon diamond

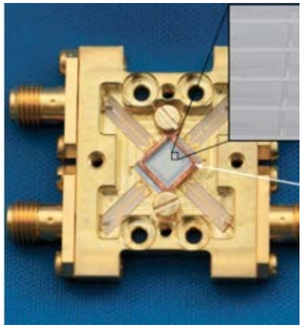
Cosmic Frontier Challenges

Broad, program with significant opportunities for progress

- UHE cosmic rays and neutrinos
  - Low rates at high energy require large exposures/aperture to make progress
- Gamma rays
  - R&D: Cherenkov and water tank arrays, Low-cost photosensors/low-power digitizers
  - Distributed timing across large arrays
- Dark Energy – next generation
  - Order of magnitude improvement in sensitivity, ~km^2 effective area, and extended energy
- Dark Matter
  - Almost every experiment is a new detector idea. There is a large program looking for larger mass, lower thresholds and directionality
- CMB
  - Large area spectrally sensitive arrays low power readout and high bandwidth DAQ







Cosmic Frontier Common Technologies

Cryogenic detectors :

- For CMB, Dark Matter and Dark Energy the new directions involve superconductor detectors.
- We want transition edge sensors and MKIDs in large arrays
- US leadership is clear in this area

SiPM Arrays:

- DM, gamma rays, UHECR want large arrays of SiPMs. Maybe even for very fast astronomical imaging.
- Low power readout and high bandwidth DAQ.
- Good opportunity for organizing a coherent effort.

ASICs:

- In many cases the future experiments involve large channel count, with power and density requirements. ASICs are the way to address this.
- Need to keep this valuable resource in the labs and available to the university community.

Intensity Frontier Recommendations

- Development of large mass, cost effective detectors for neutrino detection and proton decay.
- R&D on cost effective calorimeters with good photon pointing and time of flight (goal is <20mrad, 10ps).
- R&D towards cost effective, high efficiency photon detection for kaon experiments (10^{-4})
- Very fast, very high resolution photon/electron calorimetry for muon experiments (goal is 100ps, sub-percent energy resolution)
- Very low mass, high resolution, high-speed tracking for muon,kaon, and light weakly coupled particle experiments (0.001 X_0 per space point, 100ps per track)
- High fidelity simulation of low energy particle interactions; strategies to effectively simulate >10^{12} particle decays & interactions.
- High throughput, fault tolerant streaming data acquisition systems (goal of TB/second throughput to PB/year data storage)

Intensity Frontier Precision

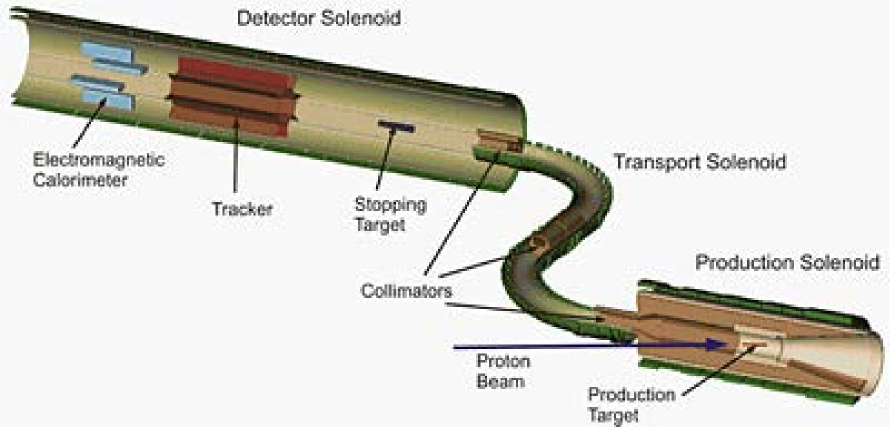
Needs for Photosensors (SiPM, MCP…)

- g-2 - $\Delta t/t$ for 2 showers
- μ->e – detection ε, moderate rad hardness
- ORCA – $\Delta E/E$, $\Delta t/t$, low dark rate, high ε

Need: large areas, lower cost, small form factor, lower dark count, active quench, rad hard, dynamic range.

Technologies: LAPPD, incremental development,

Digital 3D SiPM technology



Golden Modes

Muons: $\mu^- N \rightarrow e^- N$, g-2, $\mu^+ \rightarrow e^+ \gamma$, EDM

Kaons: $K \rightarrow \pi \nu \nu$

B: $B \rightarrow \mu\mu$, $B \rightarrow Kll$, $B \rightarrow s\gamma$, $B \rightarrow \tau\nu$

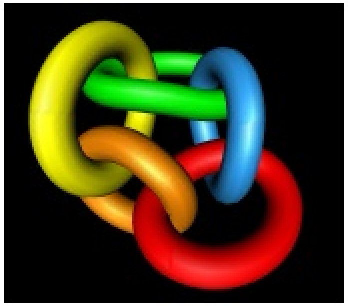
Presentations given for following technology areas

- ASICs
- High-speed systems
- Pixelation
- Photodetectors
- Trigger/DAQ
- Emerging Technologies
  - Quantum dot doping, 3D printed sensors, spectrally sensitive CCD, micro-machining cooling, micromachining active edge sensors

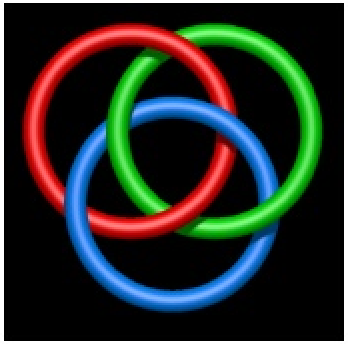
- See slides in backup for more details

Types of R&D

Here in Frontierland our R&D is divided into project-driven and generic



Transformational Generic Detector R&D and grand Challenges at the multimillion dollar level. Examples: LAPPD, large area, low radioactivity, photodetectors with high efficiency at LAr and LXe scintillation wavelengths, wavelength sensitive pixels for astrophysics.



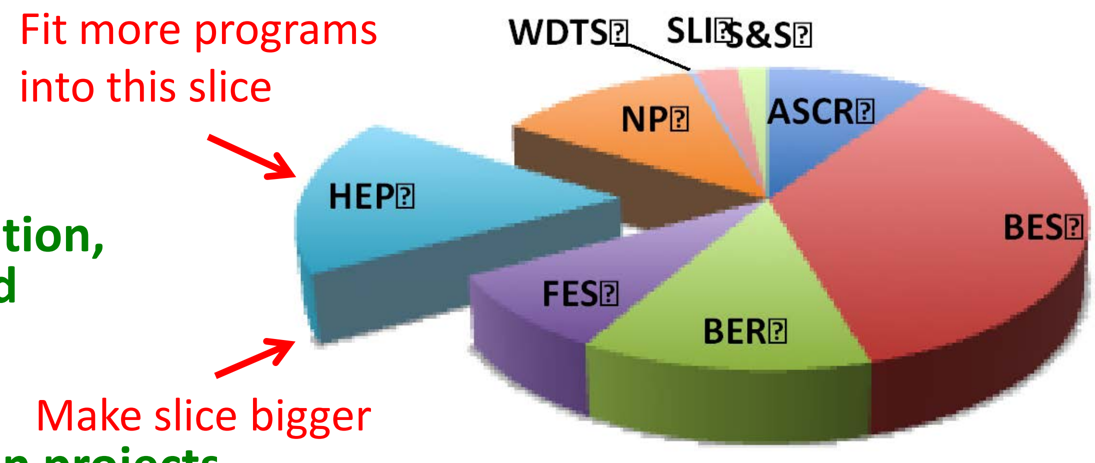
Generic Detector R&D which is motivated by common needs in instrumentation among several experiments or which may increase reach or reduce costs of future HEP experiments. Examples: Lab KA25 funding, University ADR program, SLAC test beam, water based liquid scintillator, compensated calorimetry, ILC detector R&D including particle flow.

Project driven Detector R&D and typically project funded. This is NOT generally funded by the generic Detector R&D program at DOE.

Strategic Goals

- **Develop more cost-effective technologies with increased reach**

1. **Develop balanced Instrumentation, based on our strengths, aligned with research priorities**
2. **Balanced funding level between projects and a program with appropriate "portfolio of risk"**
3. **Develop process for integrating universities, national laboratories, other branches of science and industry**
4. **Create opportunities for careers in HEP instrumentation**
5. **Identify opportunities for technology transfer and collaboration with other sciences**



Office of Science 2013 Budget

CPAD
Coordinating Panel for Advanced Detectors

The community has established a Coordinating Panel for Advanced Detectors to foster these strategic advances in instrumentation by coupling the unique resources of the National Labs, our world-leading research universities and industry.

- CPAD Membership:

- From Universities
  - Jim Alexander, Cornell
  - Marina Artuso, Syracuse
  - Ed Blucher, Chicago
  - Ulrich Heintz, Brown
  - Howard Nicholson, Mt. Holyoke
  - Abe Seiden, UCSC
  - Ian Shipsey*, Purdue
- From laboratories
  - Marcel Demarteau*, Argonne
  - David Lissauer, Brookhaven
  - David MacFarlane, SLAC
  - Ron Lipton, Fermilab
  - Gil Gilchriese, LBNL
  - Bob Wagner, Argonne
- International
  - Ariella Cattai, CERN
  - Junji Haba, KEK

(*) co-Chair

http://www.hep.anl.gov/cpad/

CPAD

Coordinating Panel for Advanced Detectors

- Formed as a recommendation of the DPF Taskforce on Instrumentation
- A standing body to “promote and assist in generic detector R&D”

CPAD was asked to oversee the Snowmass Instrumentation Frontier

CPAD has given priority to and is integrated into the Snowmass process.

CPAD work on:

- Coordinating the national instrumentation program,
- Coordination of instrumentation resources at National Labs for the HEP community
- Development of interdisciplinary links, and links to industry
- National Instrumentation Fellowships,
- National Prizes

Is expected to begin as Snowmass concludes

We expect CPAD to help execute the vision initiated here

Backup

Snowmass 2013 Instrumentation Frontier Brief Summary

G. Haller, 8-23-13

Our vision is for the US to have an instrumentation program for particle physics that:

- Enables the US to maintain a scientific leadership position in a broad, global, experimental program
- Develops new detection capabilities that provides for cutting edge contributions to a world program

Our goal for Snowmass was to develop that vision by establishing the physics needs for future instrumentation in each frontier, technological opportunities, and possible paths forward

Snowmass 2013 Instrumentation Frontier Brief Summary

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Here in Frontierland our R&D is divided into project-driven and generic.

Projects develop technologies necessary for a specific experiment. They do not maintain infrastructure and cannot afford to take substantial risks. Generic R&D has fewer constraints. Both are needed.

Project Driven

- SiPMs for LHC HCAL
- Cold Electronics for LBNE
- CCDs for LSST
- DAQ systems for LHC

Generic

- Large area photodetectors
- 3D electronics
- SLAC test beam
- Crystal calorimetry

Generic R&D Program	Status	Characteristics
Water Based Scintillator	Ready for test deployment	7x cheaper than oil base
Large Area Photodetectors	1st prototype under test	Utilize microchannel plates and ALD for fast, large area
SLAC Test Beam	Available	Pulsed electron beam
High Speed optical modulation	Considered for ATLAS	106 lower error rate than vxcels, rad hard, low power
High Pressure Xenon Gas	Data evaluation	Possible nuclear recoil direction detector
3 Dimensional Electronics	Demonstration MP run complete	Stack heterogeneous layers of electronics and sensors
Liquid Argon Purity	Complete	Test materials for LA systems
Compensated Calorimetry	In progress	Hadron calorimetry resolution improvement
Digital Hadron Calorimeter	Complete, data analysis	Imaging calorimetry
QUPID Phototube development	Prototype	Procured by Hamamatsu

Diagonalization

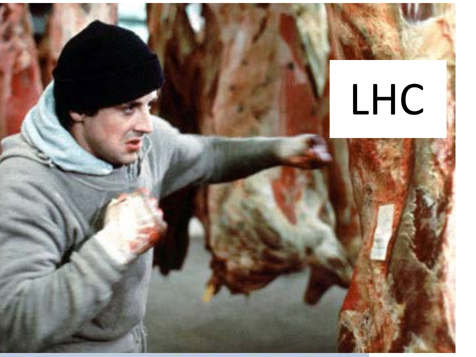
Some of the following discussion may seem diffuse, but there are strong themes that pervade the technologies and frontiers

Technology	Implementation
Pixelization	Silicon pixels, MKIT, CCD, LAPPD, MSGC->large area
ASIC and electronics	Everywhere…
Trigger and DAQ	Stream everything if possible, intelligent front ends
Mechanics and power	Low mass materials, foams, power conversion
Photosensors	SiPM, MCP, Cathodes-> large area, fast
Speed	Fast silicon, crystals, photosensors, electronics
Resolution	Crystals, dual readout or PFA calorimeters,

We will see how these themes emerge from physics needs at the Frontiers

Energy Frontier Challenges in e^+e^- – ILC/CLIC

(Stanitzki)



- Calorimeter granularity
  - Need factor ~200 better than LHC
- Pixel size
  - Need factor ~20 smaller than LHC
- Material budget, central tracking
  - Need factor ~10 less than LHC
- Material budget, forward tracking
  - Need factor ~ >100 less than LHC

Energy Frontier -Muon Collider

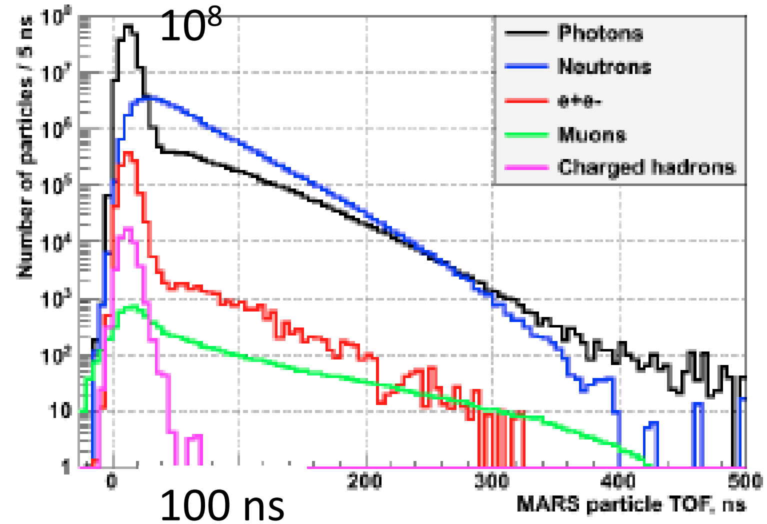
(Mazzacane)

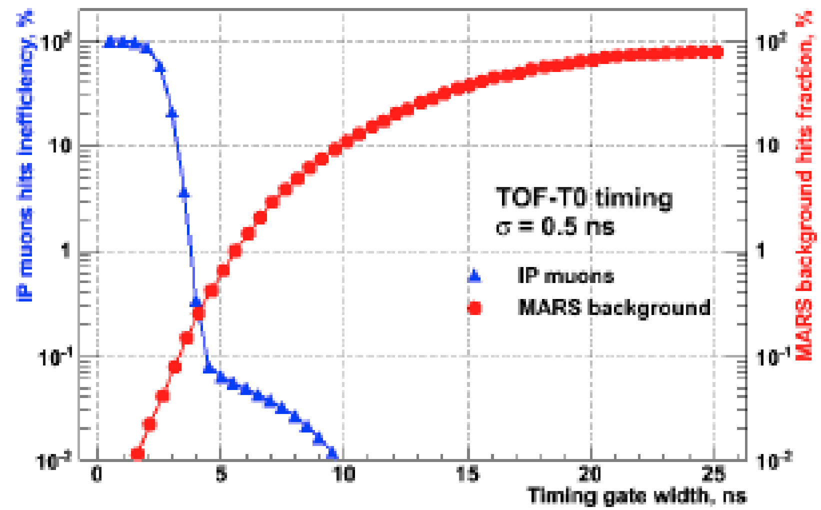
The muon collider is a possible path to a multi-TeV lepton collider

- Can we do physics in the huge backgrounds from beam decay?

Full simulation of beam backgrounds combined with physics simulation and reconstruction

- Hundreds of TeV/crossing
- But backgrounds are soft and out of time
- 1 ns time cut reduces tracker background by 10^3!
- Pixelate to reduce occupancy
- 1-10 ns cuts reduce background x 100 in calorimeter





Fast Timing

Intensity Frontier Instrumentation Needs

Calorimeters

- **Fast (Mu2e→LYSO, g-2→PbF2, MEG→ LXe, ORKA→Pb-scint.)**
- **$\varepsilon_{\pi 0}$ >99.9999% (K→πνν) with 4π fully hermetic photon detection**
- **KOPIO+ needs energy, time, position and direction**

Trackers:

- **Low mass (drift chambers, straws, Si)**
- **Good space/timing resolution**
- **Operation in vacuum (e.g. g-2, Mu2e, NA62/CKM straws in vacuum)**

Massive Detectors:

- **Need cost effective detection of scintillation or Cherenkov light**
- **Need cost effective detection of ionization electrons**

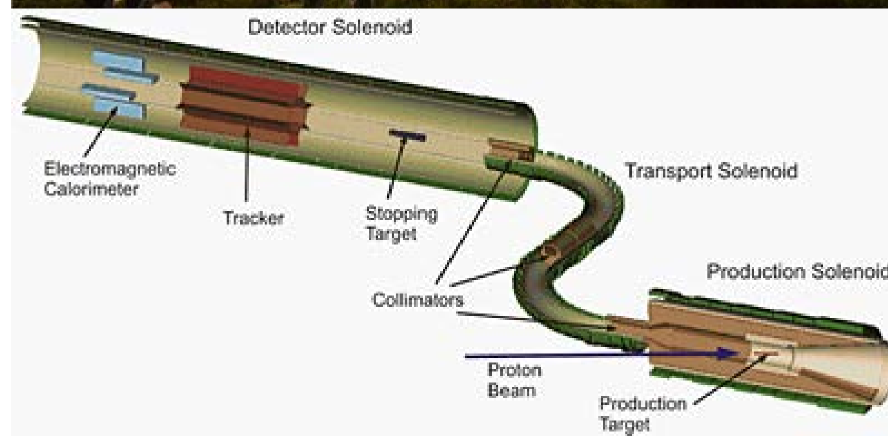
DAQ

- sensitivity gains afforded by the high-level processing of all events

Simulations and Computing

- reasonably and economically steward 1-10 Peta-Bytes
- Include neutrino-nucleus interactions within GEANT4

Intensity Frontier Precision



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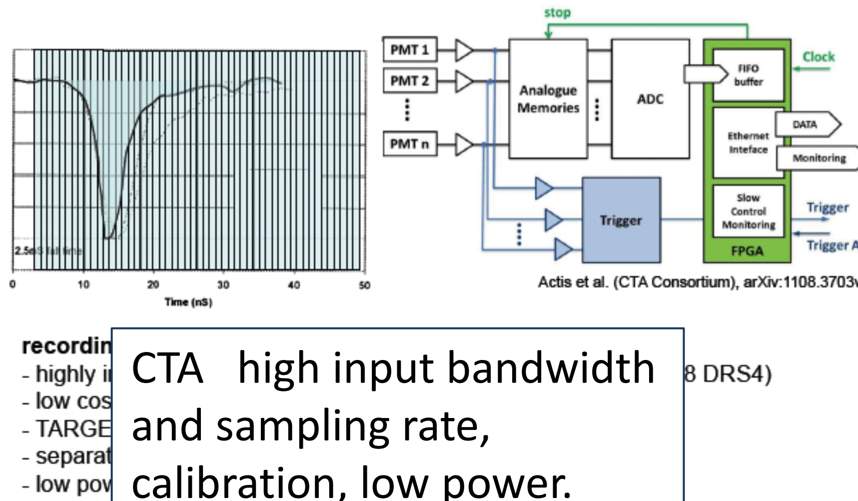
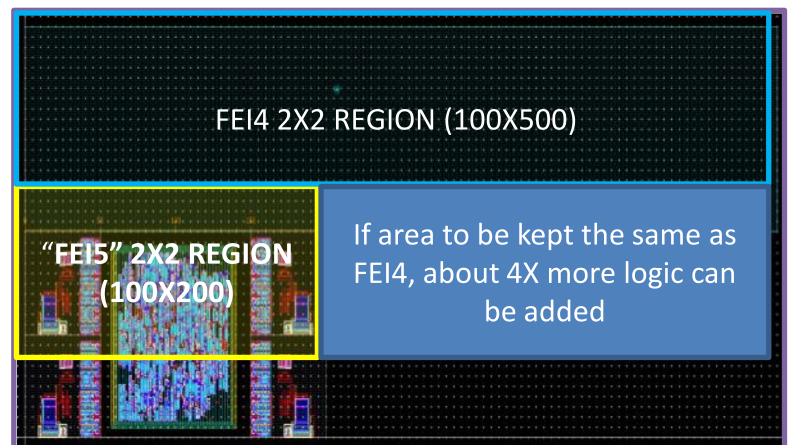
Use of ASICs

(Haller)

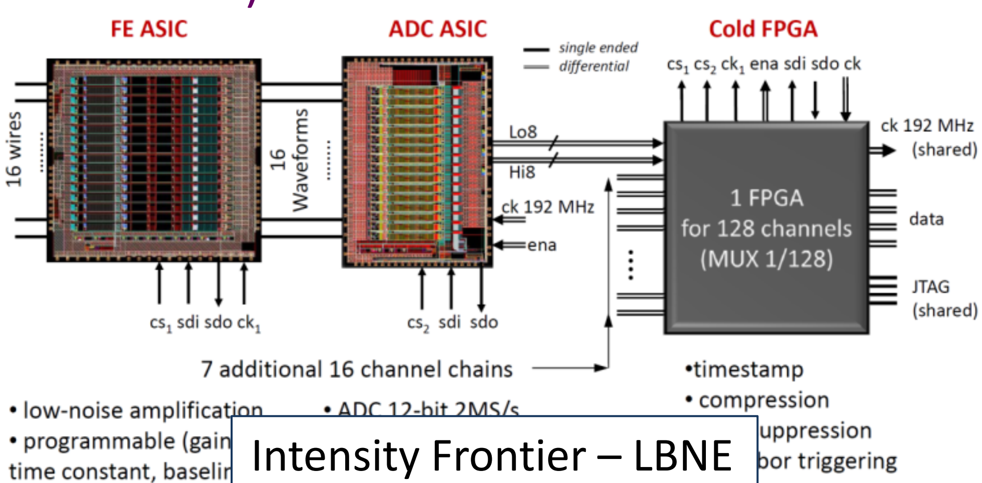
- ASICs are in most of the HEP experiments.
- Essential to get science (size, performance, power, etc):
  - ~ 50 ATLAS ASICs (currently < 15 with US participation)
  - ~ 30 CMS ASICs (currently ~5 with US participation)
  - ~ 6 LHCb ASICs (Europe based)
  - ~ 40 ASICs for other experiments (~30 US based)



CTA high input bandwidth and sampling rate, calibration, low power.



Energy Frontier – ATLAS Pixel Large ASICS, collaboration



Intensity Frontier – LBNE Cold electronics

ASIC R&D

- ASIC-related R&D is required in a number of areas in order to improve science output or simply make possible future experiments in the intensity, cosmic, and energy frontiers. Examples are:
  - High-speed waveform sampling.
  - Pico-second timing.
  - Low-noise high-dynamic-range amplification and pulse shaping.
  - Digitization and digital data processing.
  - High-rate radiation tolerant data transmission.
  - Low temperature operation.
  - Extreme radiation tolerance.
  - Low radioactivity processes for ASICs.
  - Low power.
  - 2.5D and 3D assemblies.
  - Power conversion/delivery.

High Speed Systems

(Varner)

Fast Timing traditionally

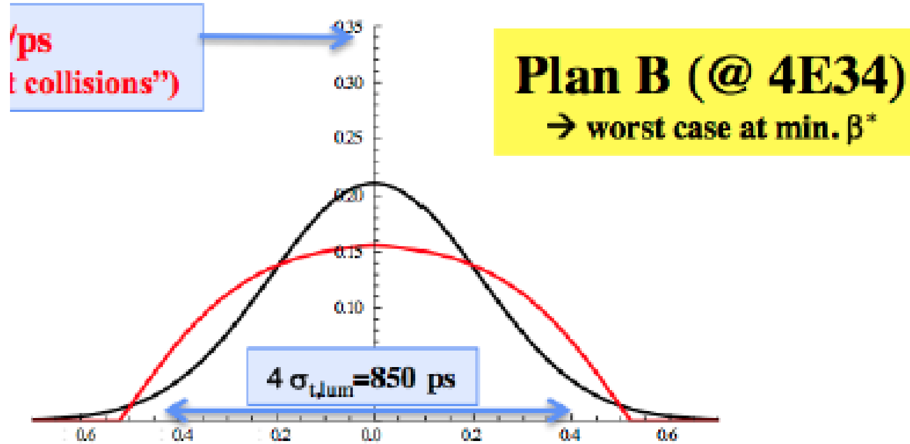
- Particle Identification
- Difficult, expensive, low-density, …

Next generation experiments

- Rare processes -> background suppression
- High statistics -> high event rates
- High event rates -> pile-up, loss of signal purity

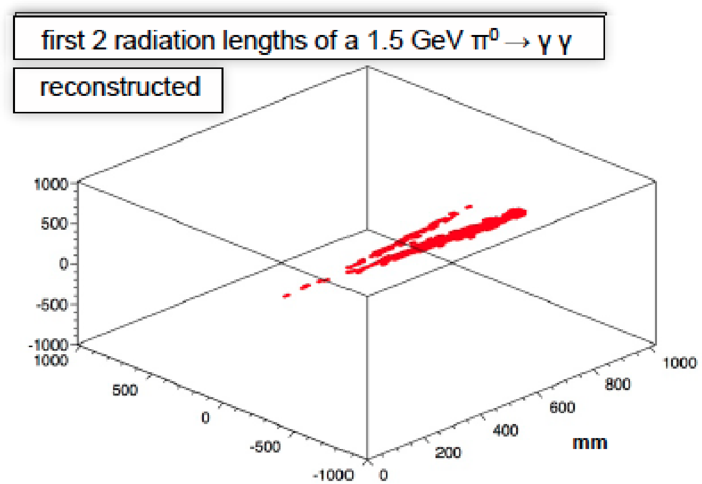
Some examples:

1. Next generation Particle ID
2. Reinvigorating older techniques
3. VH-LHC event pile-up
4. Even at trigger level



LHC IP time spread

Improvements in spatial and timing information could enhance background rejection and vertex resolution in large water Cherenkov detectors.



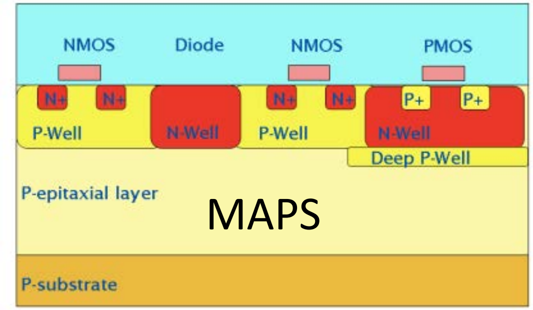
Pixelization

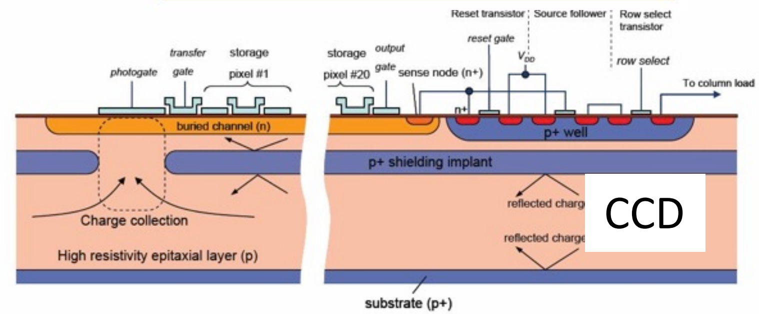
Low mass, pixelated radiation hard detectors will be needed for ATLAS, CMS, an ILC, CLIC or muon collider in the energy frontier, and LHCb and next generation B or tau factories in the intensity frontier.

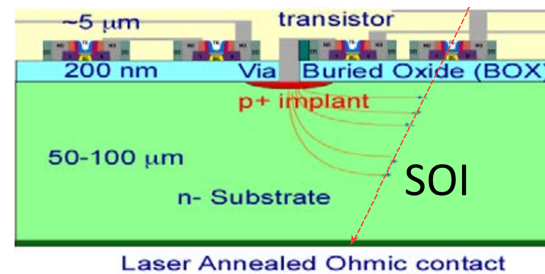
- Often requires sophisticated in-pixel processing such as time stamping, cluster finding or inter-cell hit correlation.

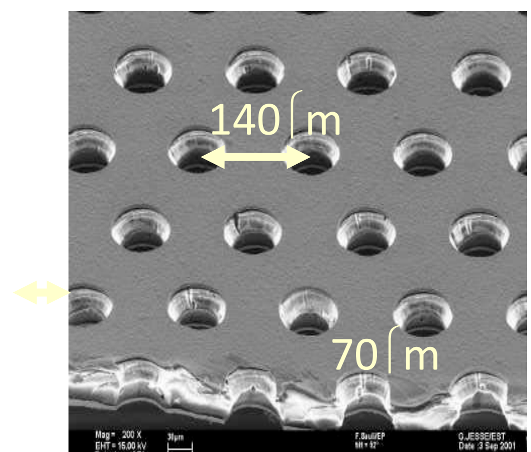
Technologies:

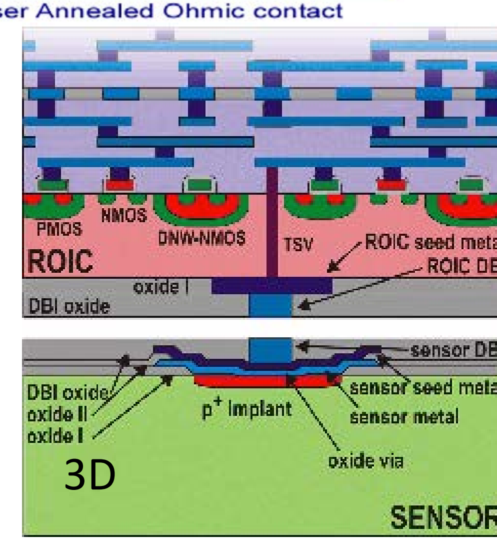
- Detector/electronics integration
- Commercial wafer-scale processes
- Microstrip gas detectors









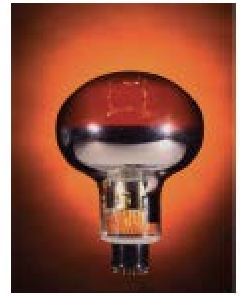


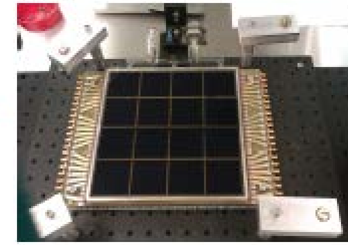
Photodetectors

Discussion of high speed, large area photodetectors and emitters pervaded our meetings.

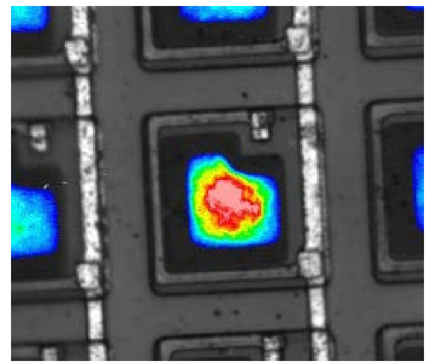
- New rad hard crystals with high light yield
- Compact solid state photosensors (SiPM). Want them:
  - cheaper, faster, quieter
  - Can we build large arrays?
- Replacements for PMTs
  - LAPPD – large area microchannel plate based development - first article is being tested.
- Spectral sensitivity

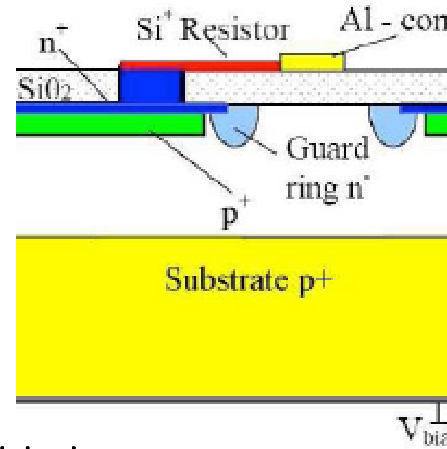
LAPPD



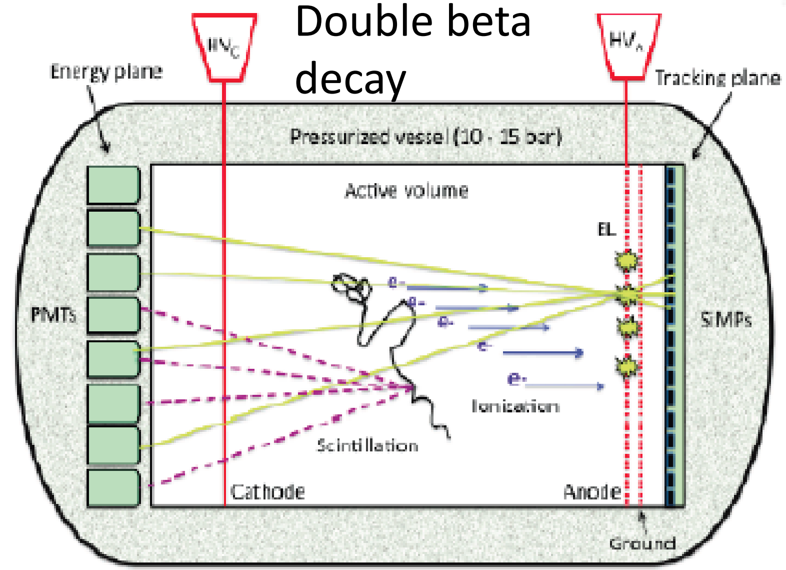


SiPM





Double beta decay



Trigger and DAQ

(Smith)

ALICE (post-LS2):Triggerless

- Readout 50 kHz Pb-Pb (i.e. L = 6×10^{27} $cm^{-1}s^{-1}$), with minimum bias (pipeline) readout (max readout at present ~500 Hz)

ATLAS (post-LS3):Triggered

- Divide L1 Trigger into L0, L1 of latency 5, 20 μsec, rate < 500, 200 kHz, HLT output rate of 5 - 10 kHz
- L0 uses Calo & Muon Triggers, generates track trigger seeds
- L1 uses Track Trigger & more muon detectors & more fine grained calorimeter trigger information.

CMS (post LS3):Triggered

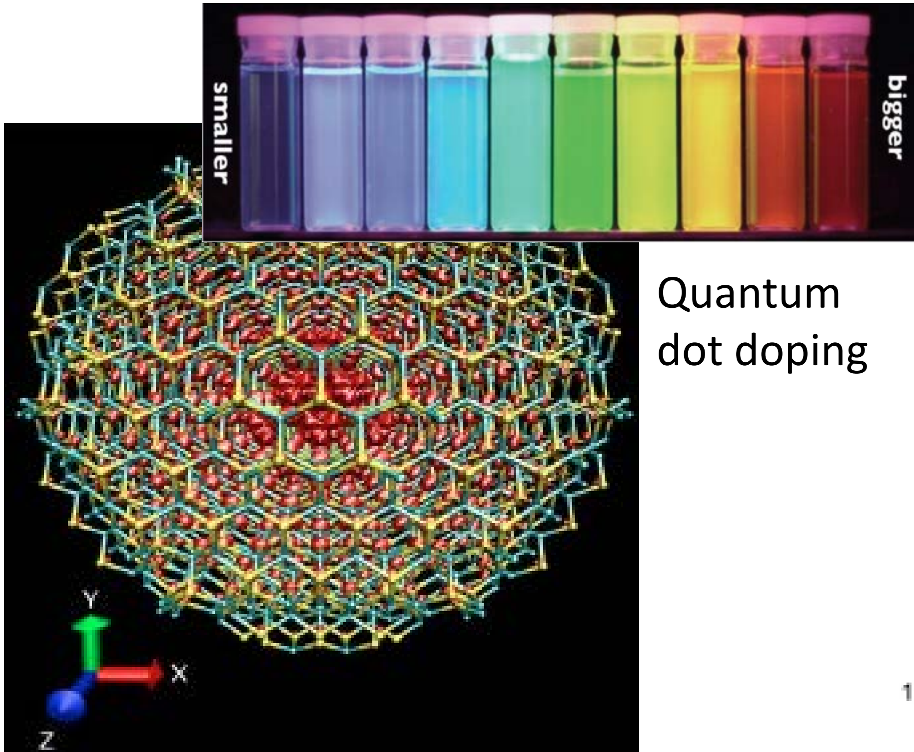
- Considering L1 Trigger latency, rate: 10 – 20 μsec, 0.5 – 1 MHz
- L1 uses Track Trigger, finer granularity μ & calo. Triggers
- HLT output rate of 10 kHz

LHCb (post LS2):Triggerless

- Execute whole trigger

Emerging Technologies

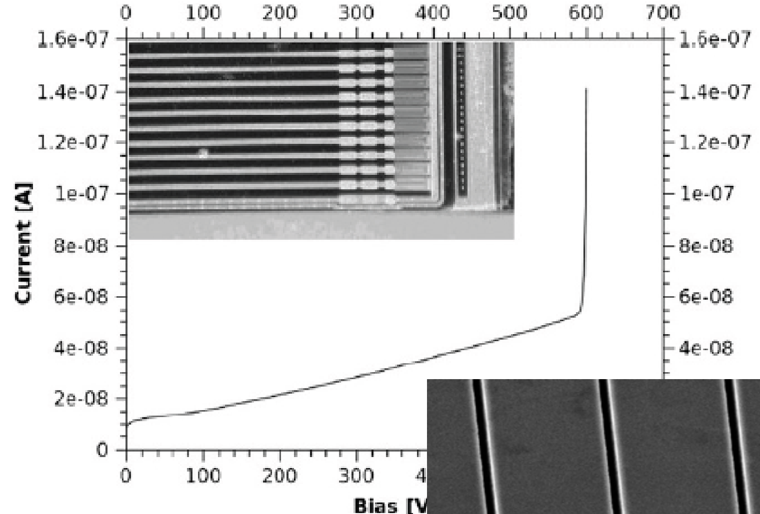
(Alexander)



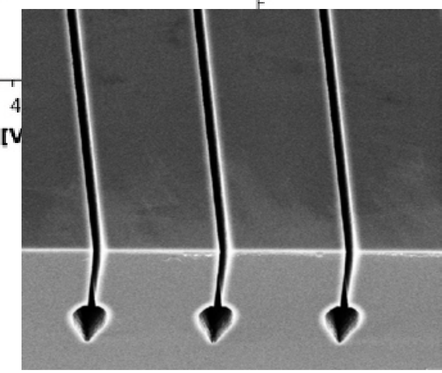
Quantum dot doping

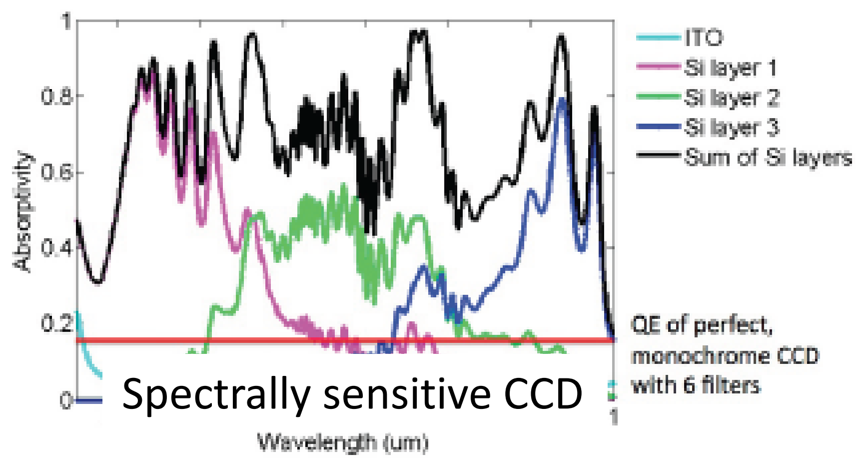
3D Printed sensors

Micromachining – active edge sensors



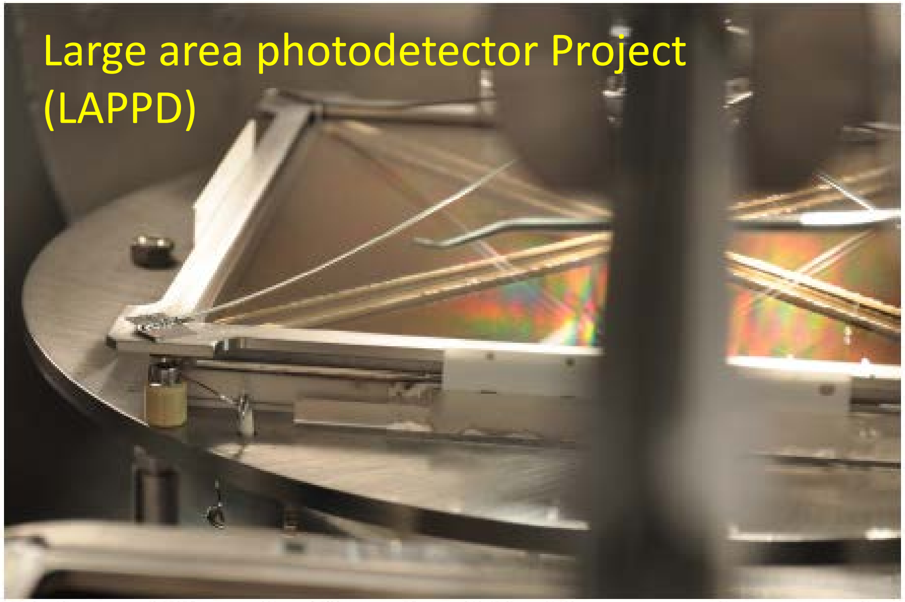
Micromachining Cooling



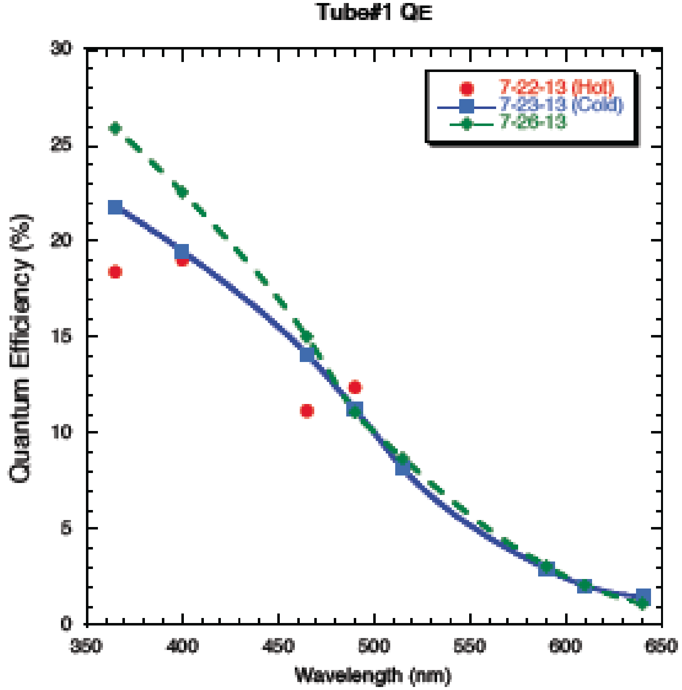


Spectrally sensitive CCD

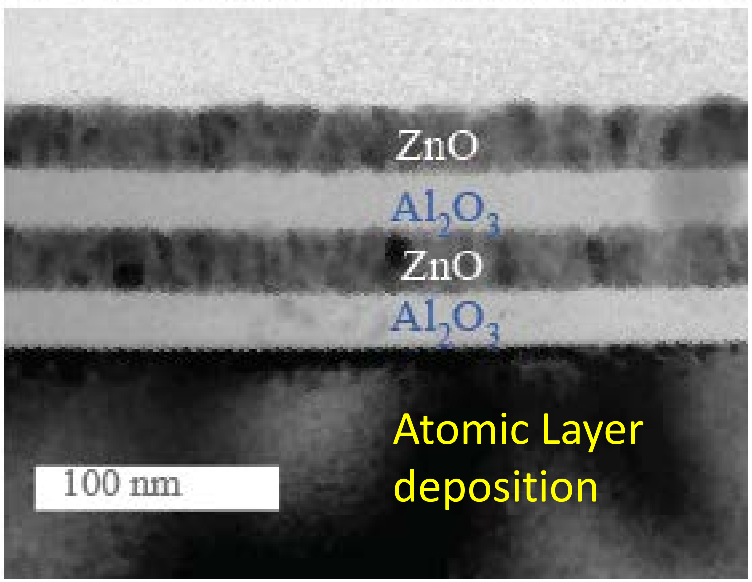
3-band with ITO gates



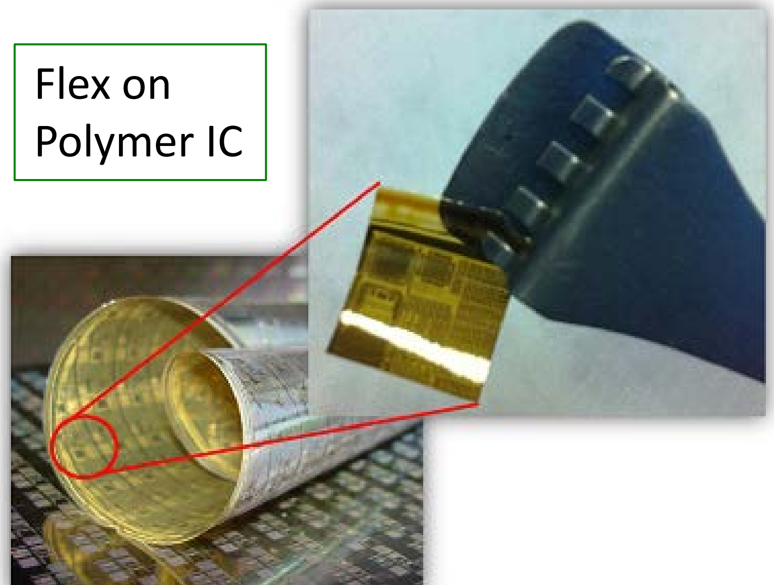
Tube with window hot indium seal completed



Can produce hybrid, layered materials

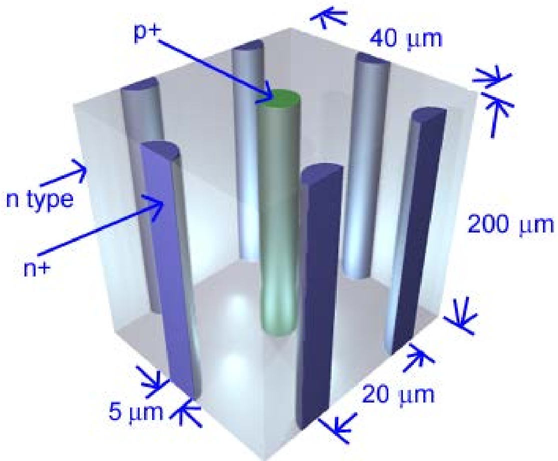


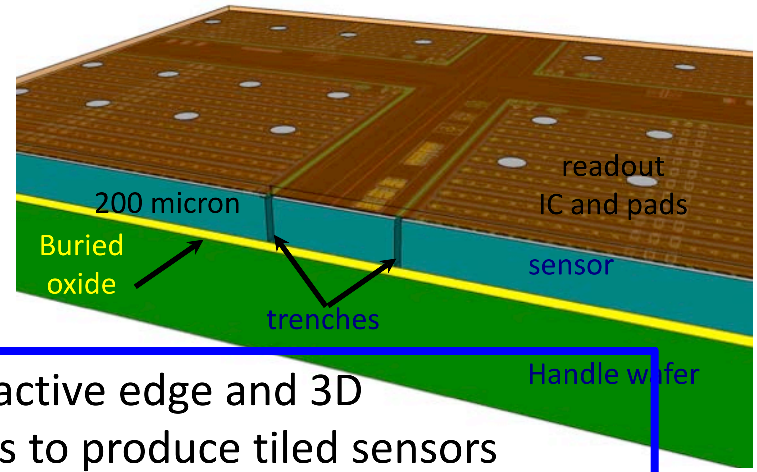
Flex on
Polymer IC



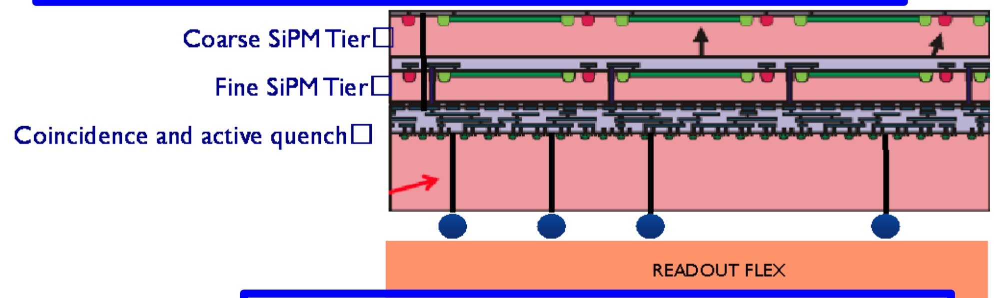
To the Third Dimension

(RL)

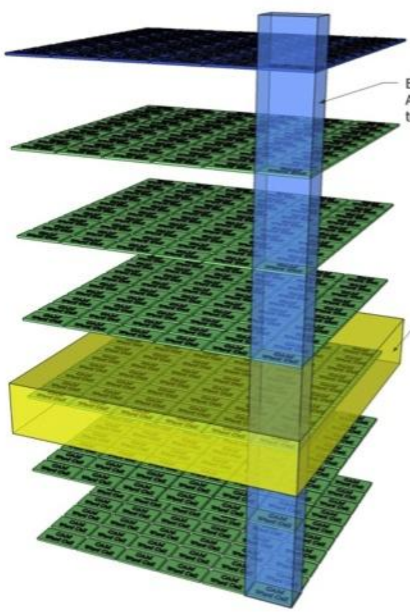




Combine active edge and 3D electronics to produce tiled sensors combined with ROICs for large area arrays

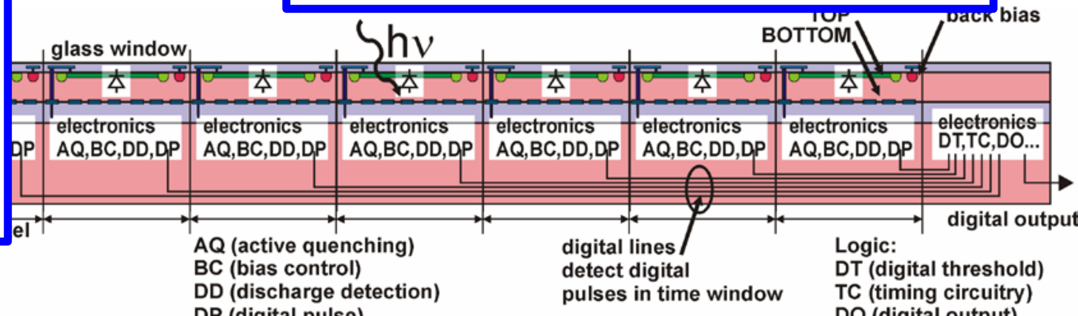


3D sensors, fast radiation hard, Active edges



CMS – Use stack of 3D tiers to emulate tracker layers for CAM –based track recognition

Use avalanche multiplication for fast, low power trackers



Use 3D to connect each SiPM subpixel to quenching, timing, and control electronics

Summary

This has been an exciting and exhausting week

- We have explored physics needs and development opportunities
- We have identified common thrusts
- We have discussed ways to maintain a vigorous program with a mix of project and generic R&D, university, laboratory, and industrial involvement.
  - This will not be easy
  - The hardest part of having vision may be to sustain it. We are all busy, and have other pressing needs.

Execution of this vision will be up to CPAD, funding agencies, and us.

Investing in R&D is investing in the future of the field: in young people, in training, In university and laboratory infrastructure, in new technologies, in cost effectiveness and in technologies that will benefit other sciences, and produce spinoffs